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Participative multi-criteria decision analysis in marine management and conservation: Research progress and the challenge of integrating value judgments and uncertainty

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ABSTRACT

Managers and practitioners have increasingly applied participative multi-criteria decision analysis (MCDA) in marine multi-objective management situations. Despite methodological advances and practical experiences, there is no systematic review that clarifies the current scope and challenges of participatory MCDA in fisheries management, aquaculture and marine conservation. Using the ISI Web of Science database, 95 peer-reviewed publications were found that report MCDA applications in marine management (fisheries or aquaculture) and marine conservation. Of these, 31 studies explicitly and systematically incorporate stakeholders' engagement at one or more stages of the MCDA process. Results show how participative MCDA has been applied in a wide range of marine multi-objective problems. Interestingly, 76% of studies included participation and 24% consultation processes. Most MCDA studies in marine environments were developed in Europe and Asia. Results highlight that despite successful experiences in participative MCDA, participation has been generally fragmented. Participatory processes have focused mainly at particular stages, such as the establishment of objectives and criteria, and elicitation of weights of importance. Conversely, other important stages of MCDA, such as identifying alternatives, estimating consequences or prioritizing management alternatives, exhibited low levels of participation and/or consultation. In addition, results suggest that uncertainties around multiple values judgments are seldom treated in marine MCDA studies. Greater rigor in promoting an active participation in the complete decision process and fully considering the uncertainties around people's value judgments are important research gaps, which if addressed, could substantially improve participative MCDA applications aimed at achieving sustainable management and conservation.

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1. Introduction

As fisheries management and marine conservation evolve to include multiple services, values and stakeholder needs, calls to include participative decision making processes in marine planning are becoming increasingly common [1,2]. To promote stakeholder engagement throughout decision making processes, scholars have developed a series of conceptual frameworks and policy design instruments [3,4]. Participative multi-criteria decision analysis (MCDA) is a family of decision making protocols aimed at promoting effective stakeholder participation [4–6]. MCDA evaluates and prioritizes multi-objective management options when monetary values or cost-benefit analysis are inappropriate [7]. Practitioners would commonly integrate multi-dimensional data (e.g. economic, social and/or ecological), giving an analytic framework to consider value judgments in decision making. MCDA aids in clarifying stakeholders' values and objectives, promoting innovation, social learning and understanding [6,8].

In marine ecosystems, participative MCDA has begun to be used to aid participatory planning approaches [e.g. [9–11]]. Despite the potential and increasing interest in using MCDA, no review clarifies the scope, challenges and emerging issues behind the application of participatory MCDA. Such a review is important as it allows to identify: (a) the main decision objectives of participatory MCDA applications, (b) the extent to which different tools/approaches are applied to engage stakeholders in the MCDA process and, (c) the way uncertainties around the integration of different stakeholder value judgments are included in the process. In this sense, the main goal of this review is to contribute to a research agenda that can inform participative MCDA design through identifying critical research gaps, which if not addressed,

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have the potential to undermine the performance of MCDA approaches for marine management and biodiversity conservation.

2. Background: the participative MCDA process

Fig. 1 presents the main steps of the participative MCDA. This process is not linear, and often practitioners develop only particular stages, depending of each decision context. The following stages have been highlighted as fundamental components in participative MCDA [4,12].

a. *Clarifying decision problem:* In an initial stage, practitioners and stakeholders explore a common understanding of the decision problem. Early stakeholder engagement allows managers to explore a wide range of values, attitudes and expectations, forecasting potential socio-environmental conflicts [13].
b. *Establishing objectives and criteria*: Meaningful participative processes are founded on clear statement of relevant stakeholders' objectives [14]. Objectives represent values, being operatiolanized by attributes or indicators. Hierarchy value trees are commonly used to articulate and organize objectives and attributes [14,15]. If based on transparent and inclusive approaches, identification of objectives may increase trust and compromise [16].
c. *Developing alternatives*: MCDA applications generally consider a limited set of alternatives. Recent studies in marine management suggest that active stakeholder participation in identifying management alternatives promotes creative solutions, implementation success and monitoring compliance [13].
d. *Estimating consequences:* Consequences are generally estimated by expert or directly by decision makers. However, in scenarios of poor-data and high levels of uncertainties, local knowledge and users experience have been critical for better estimation of ecological and social consequences [1,11,17].
e. *Evaluating trade-offs and weights*: Fundamental to any MCDA method is to establish the relative importance of the different objectives and criteria which stakeholders must decide upon. Relative importance of objectives can be represented in weights, which express a value judgment of the gain in the number of units of one attribute that compensates for loss on another [7,18]. Different methods have been used to establish weights of importance among objectives. The Analytic Hierarchy Process (AHP) is one of the most widely applied participative decision making protocols to prioritize objectives and alternatives. AHP analysis develops a set of pairwise comparison matrices, expressing the intensity of preference in a nine-point scale [19]. Alternatively, the swing weight method also allows the identification of key value trade-offs, focusing specifically in the range of consequences in the specified decision problem (worst and best outcomes for the whole set of alternatives) [7].
f. *Prioritizing alternatives*: Several MCDA methods have been applied to prioritize management alternatives. Most of them are based on additive value functions or dominance approaches (Outranking) [7,18].

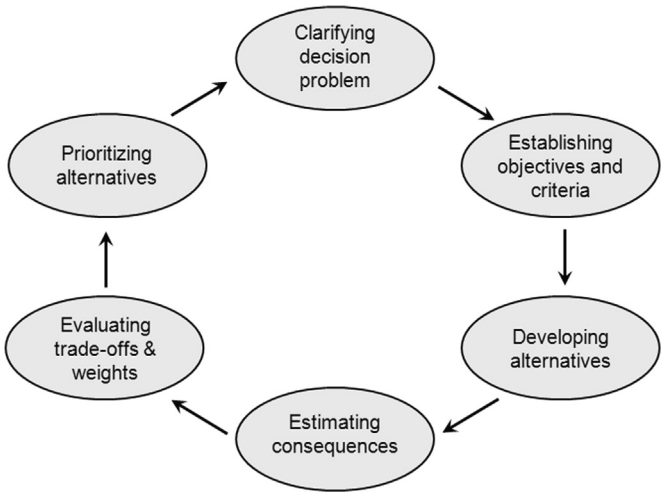

Fig. 1. Stages in a participative MCDA process [Modified from [4]].

This paper explores how researchers and practitioners have engaged stakeholders at different stages of participative MCDA in marine management and conservation. The paper also examines the diverse approaches used to consider uncertainties and multiple value judgments in the decision making process.

3. Materials and methods

A systematic search of the peer-reviewed literature in the Web of Science (ISI) database (SCI-EXPANDED, SSCI, A&HCI) was executed by using the following keywords: "*multi-criteria*", *multi-criteria*, "*multiple criteria*", *outranking*, "*analytic hierarchy process*", *AHP* and "*structured decision making*". All these terms were combined (AND) with *aquaculture, fisheries* and *marine*, avoiding duplication of papers. These queries resulted in 198 English-language papers published between January 1989 and August 2014.

The abstracts of these 198 papers were examined. A sub set of 91 papers that reported unequivocal applications of MCDA in fisheries management, aquaculture or marine conservation were selected. The 107 papers that did not meet this criterion were excluded. The excluded papers were typically literature reviews, software or operational models developments, marine transportation, ships engineering or ship marine design, technology diffusion, infrastructure projects, power generation, or morphological or physical analysis, which had no relation to participation processes in marine management or conservation. Because the set of keywords could leave out relevant papers that do not include the filter terms in the title, abstract, or keywords, the references of the 91 selected papers were examined. From this analysis a further four papers, also available in the Web of Science (ISI) database, were selected. Each of the final 95 papers was classified according to two broad areas: marine conservation and marine management (which included papers on aquaculture and fisheries). Then, the main decision objective was identified for each paper. The geographical distributions of case studies were also recorded.

From the list of 95 papers, 31 papers explicitly and systematically reported stakeholders' engagement at one or more stages of the MCDA process. The methods described to engage stakeholders in each of the 31 papers were recorded and classified, differentiating between participative or consultive process. A consultation process was broadly defined as *a two-way relationship in which citizens provide feedback to government* [20]. Participation was understood as *a relationship in which citizens actively engage in defining the process and content of policy-making* [20].

The analysis also explored how researchers and/or practitioners managed uncertainties around weights of importance in the decision making process. The different approaches and mechanisms to report uncertainty in the value models were classified in: (1) group coherence and cluster analysis, which refer to mechanisms to estimate the internal coherence of weights in a particular group [21]. (2) Sensitivity analysis, which refer to mechanism to estimate the sensitivity of alternatives' performance to variations in weights [22]. (3) Different value models, which refer to structure a specific set of weights for each stakeholder group,

representing discrepancies in people's value judgments [7].

4. Results

4.1. MCDA applications in marine management and conservation

MCDA has been mostly applied in fisheries management and aquaculture (69%) ($N=66$), with less applications in marine conservation ($N=29$). Table 1 shows the wide range of decision objectives identified in the 95 reviewed papers. In marine management, allocating aquaculture sites was the most common decision objective (23%). Interestingly, 20% of papers focused on planning sustainable fisheries, integrating a range of economic, ecological and social data into decision models. Similarly, in marine conservation, allocating marine protection areas was one of the most common objectives (21%), together with evaluating marine vulnerability to hazards (e.g. climate change, pollution) (21%) and allocating sediment disposal areas in marine environments (14%).

MCDA is an area of increasing development in marine management and conservation (Fig. 2). In fact, 80% of the papers included in the review have been published after 2006. Participation and/or consultation processes were restricted only to 33% of the papers ($N=31$). The geographic distribution of case studies shows a dominance of Europe (37%) and Asia (22%) (Fig. 3). Remarkably, Africa and Australia had the highest proportion of case studies with participation or consultation, 67% and 54% respectively.

4.2. Stakeholders consultation/participation in different stages of MCDA

Thirty one papers explicitly reported participative MCDA applications, describing specific participative or consultive decision making process. Interestingly, a general tendency to apply participative methods was found (76%) (Table 2). However, the degree of stakeholders' engagement varied across the reviewed papers (Fig. 4). Thus, the participative processes in MCDA have not been homogeneous. In some cases, the participation of stakeholders was a central aspect in the whole multi-criteria process [e.g. [23–25]]. Nevertheless, participation or consultation generally focused on particular stages, such as establishment of objectives, criteria and the elicitation of weights [e.g. [26,27]].

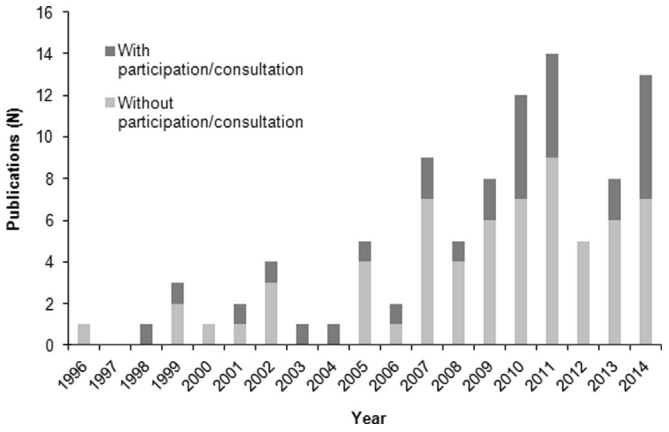

Fig. 2. Year of publication of the papers included in the review. The color of the bars represent the presence or absence of participation and/or consultation process (total $N=95$).

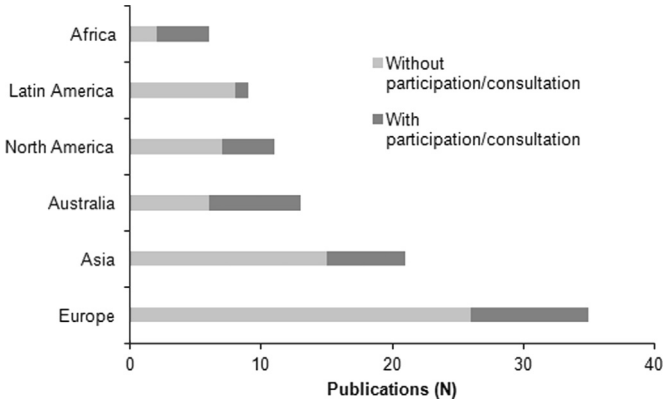

Fig. 3. Geographic distribution of case studies included in the review. The colour of the bars represent the presence or absence of participation and/or consultation processes (total $N=95$).

Over the next section, specific participative and consultive techniques indentified in the review are described, which have

Table 1
Decision objectives of MCDA in marine management ($N=66$) and marine conservation ($N=29$).

Decision objectives for marine management	Partic./Consul.			Decision objectives for marine conservation	Partic./Consul.		
	Without	With	Total		Without	With	Total
Allocating aquaculture sites	15	0	15	Allocating marine protection areas	2	4	6
Planning sustainable fisheries	8	5	13	Evaluating marine vulnerability to hazards	6	0	6
Evaluating fisheries environmental-economic impacts	4	2	6	Allocating sediment disposal areas	4	0	4
Evaluating fisheries performances	4	1	5	Integrating stakeholders' perceptions in marine protected areas management	0	4	4
Integrating stakeholders' perceptions in fisheries management	0	4	4	Evaluating marine environment quality	2	0	2
Allocating fishing rights or stocks	1	2	3	Planning sustainable marine protected areas	0	2	2
Evaluating pollutants in aquaculture	3	0	3	Evaluating human pressures on marine environments	1	0	1
Forecasting fishery grounds	3	0	3	Evaluating marine ecosystem services	0	1	1
Optimizing catching or harvesting	3	0	3	Evaluating resilience in coastal environments	1	0	1
Evaluating the importance of fisheries' objectives	0	2	2	Managing conflicts in multi-use coastal area	0	1	1
Managing incidental catch in fisheries	2	0	2	Prioritizing research needs in marine conservation	0	1	1
Optimizing feeds for farmed fish	2	0	2	Total	16	13	29
Developing stock abundance model	1	0	1				
Evaluating spatial management in fisheries	1	0	1				
Evaluating stakeholder attitudes towards aquaculture	0	1	1				
Evaluating the importance of social objectives in fisheries	0	1	1				
Prioritizing research needs in fisheries	1	0	1				
Total	48	18	66				

Table 2
Consultation and participation activities in the MCDA process ($N=31$ papers).

Stage of MCDA	Consultation	Participation
Clarify decision problem	Stakeholders' perceptions are elicited trough opinion surveys and interviews. Consultation is also developed in formal or informal meetings ($N=2$) [11,49]	In MCDA-based workshops, a shared understanding of the problem is developed, incorporating stakeholder values ($N=5$) [21,23,25,28,50]
Formulating of objectives and criteria	Objectives and criteria are identified using interviews and surveys to stakeholders. Then, focus group and workshops are organized to validate the hierarchy structure of objectives ($N=6$) [27,31,36,37,51,52]	In MCDA-based workshops, objectives and criteria are jointly established by multiple stakeholders. In collaborative group discussions objectives and criteria are organized on hierarchical value trees or cognitive maps ($N=14$) [9,21,23,25,28–30,32,35,49,50,53–55]
Identifying alternatives	Previously identified alternatives are validated in group discussions, interviews or surveys ($N=3$) [27,51,56]	Alternatives are developed in committee or group discussions with stakeholders and experts ($N=2$) [24,32]
Estimating consequences	Stakeholders are directly interviewed to estimate economic and social impacts ($N=2$) [23,32]	Working groups of experts and stakeholders jointly score alternatives against objectives, generally achieving group consensus. In one experience, representatives of stakeholder participated collecting data in the field ($N=5$) [9,11,24,25,38]
Resolving tradeoffs	Management teams established weights, based in interviews of stakeholders and literature reviews ($N=3$) [11,51,56]	Multi-criteria techniques are used to elicit objectives' weights ($N=27$). (a) AHP individual questionnaires: ($N=16$)[10,21,24,26,27,31,33–37,39,49,52,55,57]. (b) AHP group consensus: ($N=4$) [9,11,29,54]. (c) Other techniques: ($N=7$) Swing weighting method [30], direct assessment of weights [53], participatory assessment method (stakeholder reach consensus) [23,25,28,32,38]
Ranking alternatives		Stakeholders prioritized alternatives using AHP questionnaires ($N=3$) [31,54,55]

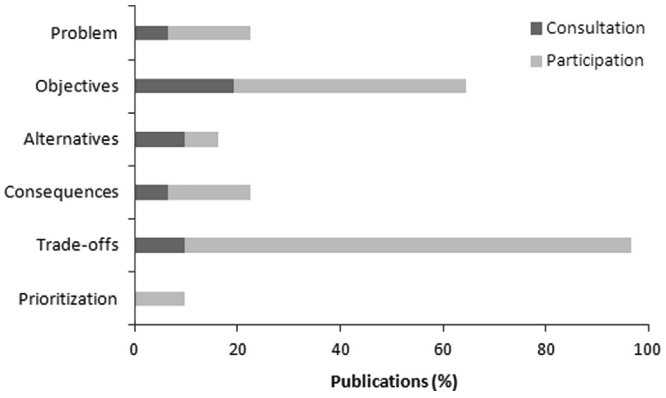

Fig. 4. The extent of consultation and participation across the MCDA stages in fisheries management and marine conservation (total $N=31$).

been used in different stages (i.e. *clarifying decision problem*, *establishing objectives and criteria*, *developing alternatives*, *estimating consequences*, *evaluating tradeoffs & weights*, *prioritizing alternatives*) of the participative MCDA (Table 2).

4.2.1. Clarifying decision problem

Only 7 papers reported engagement of stakeholders in this stage (23%). In participative approaches, practitioners organized workshops or focus groups to clarify decision problems with direct stakeholder involvement. Generally, this stage was directly linked with the establishment of objectives and criteria stage. However, most studies did not provide specific descriptions of participative techniques for clarifying decision problems. An important exception described the use of cognitive and causal maps to organize problems in participative post-it brainstorming sessions [28].

Three studies focused on a consultation approach (10%). In these cases, practitioners developed interviews, group discussions and surveys to identify stakeholders' perceptions about the decision problem.

4.2.2. Establishing objectives and criteria

Consultation and participation were relatively frequent practices in this stage (64%) ($N=20$). Most of the experiences developed participative process to identify and define objectives and criteria ($N=14$). Different techniques were used to develop a common understanding of fundamental objectives, such as causal maps [28], participatory assessment method [29], cognitive maps [30], brainstorming [25], and conflict resolution matrices [9]. Finally, to organize decision objectives, tools like hierarchical value trees or decision maps were commonly used ($N=12$).

In consultation processes ($N=6$), opinion surveys or face-to-face interviews were used to gather information about stakeholders' perceptions. Afterwards, some experiences developed focus group or workshops to validate the hierarchy structure of objectives [27,31].

4.2.3. Developing alternatives

Few publications reported stakeholders' engagement in the identification of management alternatives (15%) ($N=5$). Two papers described an explicit and systematic participative process, based on a formal multi-sectorial committee [24] and long-term working group meetings with stakeholders and experts [32].

Consultation experiences ($N=3$) were based in stakeholders' feedbacks to validate previously identified alternatives, developing focus groups, interviews or surveys.

4.2.4. Estimating consequences

Seven papers reported consultation or participation in the estimation of consequences (23%). In the participative approaches, practitioners developed working groups between experts and stakeholders, which jointly estimated impacts ($N=5$). Some experiences promoted group consensus [11,25] others developed

specific algorithms to aggregate stakeholders' estimations [24]. In addition, one study reported a participative process in which stakeholders designated representatives to collect data in the field, promoting confidence and collaboration among groups [9].

In consultation approaches, practitioners have applied questionnaires [23] and contingent valuation surveys [32] to estimate economic and social impacts and preferences.

4.2.5. Evaluating trade-offs

In the review, practitioners described high levels of participation in this stage (97%) ($N=30$). The Analytical Hierarchy Process (AHP) was the most common method, used in the 67% of the participative experiences ($N=20$). Generally, practitioners applied individual questionnaires (on-line and face-to-face) to a sample of stakeholders ($N=16$). A wide range in the number of respondents was found: from 745 individuals [33] to less than 30 [34]. In four papers, practitioners developed MCDA-based workshops to achieve stakeholders' consensus in terms of the pairwise comparison of criteria, using AHP protocols. Other techniques were also reported, such as the swing weight method ($N=1$) and the participatory assessment method (group consensus) ($N=5$).

In contrast, for consultation approaches practitioners directly assigned weights to each objective, according to secondary information and previous interaction with stakeholders ($N=3$).

4.2.6. Prioritizing alternatives

Nineteen papers (61%) reported results in this stage. In only three papers (10%), management alternatives were subject of direct stakeholder prioritization. They all used a pair-wise comparison AHP protocol. In the other cases ($N=16$), diverse algorithms were used for alternative prioritization, most of them additive value function or concordance analysis, which do not consider stakeholder participation in this stage.

4.3. Managing uncertainties for multiple value judgments

Fig. 5 presents the approaches used to consider the dispersion of value judgments among individuals. Eleven papers (35%) did not consider any kind of uncertainties or sensitivity analysis for the value judgments. For the other 20 papers, the most common approach was to develop different value models (set of weights) for each group of stakeholders ($N=10$) [e.g. [10,32,35]]. These weights were generally based on group consensus, without statistical information about the dispersion of weights.

In 14 papers (45%), practitioners elicited individual weights from a sample of stakeholders, calculating statistical distributions, means and standard deviations. In 6 papers (19%), group coherence and cluster tests estimated the internal coherence of weights for each stakeholder group [e.g. [10,36,37]]. As a logical result, the cluster groups presented higher level of internal coherence than stakeholders groups.

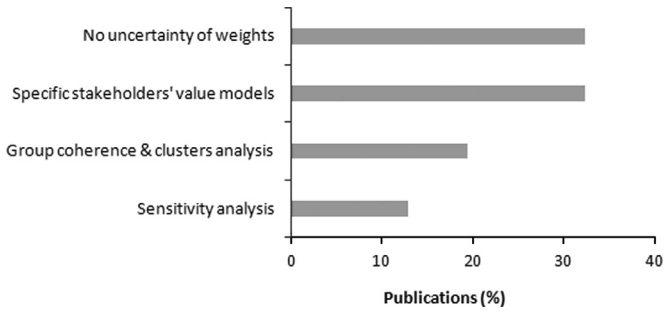

Fig. 5. Methodological tools managing uncertainties of multiple value judgments of MCDA applications in fisheries management and marine conservation (total $N=20$ papers).

Finally 4 papers (13%) reported sensitivity analysis of alternatives performance, considering variation on the weights. These results were reported in boxplot and whisker diagrams [26], percentage of change in the weighting that result in a ranking cross over [25], cumulative probability distributions of the overall alternatives' performance [24] and Monte Carlo analysis [38].

5. Discussion

The results of this review suggest that MCDA is an area of increasing interest in fisheries management, aquaculture and marine conservation. A wide range of decision objectives were identified, such as resource allocation, planning of marine protected areas, among others. This heterogeneity shows MCDA's flexibility to support decision making in a variety of marine scenarios.

Participative MCDA in marine management and conservation has mostly focused on identifying fundamental objectives from stakeholders and resolving complex tradeoffs among objectives and criteria. In other important stages of MCDA, such as identifying alternatives, estimating consequences or prioritizing management alternatives, low levels of stakeholder consultation or participation were reported. These critical aspects of the MCDA process were generally restricted to management teams and experts. This fragmentation of the participative component in the decision making process may be related with power dynamics, methodological limitations or subjective apprehensions about the technical background required to make technical estimation of some environmental consequences [6].

Growing evidence from MCDA applications in other types of ecosystems suggest that effective participation throughout the whole decision making process can improve the quality of available information in scenarios of high uncertainty and poor data [6,17,40]. Particularly in marine management, the role of local fishers in monitoring and collecting field data, proving technical inputs of ecological dynamics is widely recognized [1,9,17]. Promoting participation in all stages of the decision making process can make explicit uncertainties and value judgments which may increase the feasibility and subsequent compliance of management actions [9,40]. Therefore, the challenge is to develop mechanisms and methodologies to integrate stakeholder participation throughout each stage of the decision making process. Observing successful implementation of participative decision making will allow to identify best practices, promoting a continuous development of theoretical frameworks [41,42]. At the same time, understanding the implications of methodological differences of each MCDA approach must also be assessed. For example, according to the results, almost 70% of articles applied AHP method to trade-off stakeholders' value judgments. Surprisingly, few other methodologies were identified (Table 2). In this sense, exploring the strengths and weaknesses of specific MCDA methods for participatory decision making is an interesting research challenge.

The management of multiple value judgments and uncertainty is an important gap in marine applications of MCDA. Capturing value judgments is a difficult task, partly because they are not evidently positive or negative in themselves, but rather depend on stakeholders' interests [13,46]. In this review, Thirty five percent of the papers ($N=11$) do not report any kind of sensitivity or uncertainty analysis about the multiple value judgments, thereby ignoring information about the range of individuals' preferences. On the other hand, only 4 papers (13%) developed sensitivity analysis to estimate the effect of weights on alternatives' performances. Sensitive analyses is important as it helps identify which objectives in the value model mostly affect the performance of alternatives, allowing decision makers to focus on the most sensitive objectives in the decision making process [10]. Interestingly,

in six papers (19%), authors used cohesion and cluster analysis to estimate the degree of similarity or dissimilarity of stakeholders' objective preference [e.g. [10,39]]. Despite these analysis provide relevant information about the relative homogeneity in the weights according stakeholders, they do not provide insights about how these similarities affect the performance of alternatives in the decision making process. In this sense, participative MCDA would benefit by developing further sensitivity analysis in marine management.

In marine governance, decision makers commonly have to evaluate trade-off and make decisions characterized by substantial uncertainties around people's values [43–45]. These decisions may trigger clashes among social groups, making it difficult to find consensus solutions. If not addressed, contrasting uses, world-views and social conflicts can hamper well-intended participatory approaches. The question about how one should incorporate the substantial variation in trade-offs encountered in multiple value judgments to inform sound decisions remains open [47,48]. The management of multiple value judgments emerges as a critical challenge in marine governance. Developing stronger methods to consider these uncertainties in the decision analysis process will promote democratic and participative decision making.

The development of scientific information, both theoretical and empirical, that fulfils the described gaps in the available MCDA literature will be critical for the adequate design and implementation of participatory MCDA.

6. Conclusion

Fisheries managers, governments and conservation agencies have increasingly incorporated practical MCDA tools to develop a sustainable participative management approach. Despite successful experiences, the engagement of stakeholders has been generally fragmented and uncertainties around multiple value judgments are seldom treated in marine MCDA studies. Promoting an active participation in the complete MCDA process and fully considering the uncertainties around people value judgments could substantially improve the outcomes of participative MCDA applications.

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